Simulated Internal Short Standard with Underwriter's Laboratory for Lithium-ion Cells Under a Space Act Agreement

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Lithium-ion battery chemistry provides the state-of-the-art gravimetric energy density and highest efficiency of battery systems available in the market today. However, with several hundred lithium-ion cell manufacturers in existence, product quality is often sacrificed for cost and quantity of production. Lithium-ion cells—with their flammable electrolyte—are highly susceptible to certain impurities, especially those with metal particles as these can compromise the separator, causing internal shorts that result in fires and thermal runaway. Several research groups and standards organizations have been studying the issue of internal shorts in lithium-ion cells due to the fires encountered in the field as well as during transportation of cells and batteries of this chemistry.

A simulated internal short test method that included crushing the cells with a blunt rod has been carried out at NASA Johnson Space Center (JSC) for more than 12 years. However, the equipment used for testing was very crude and is manually operated, which prevents it from being converted into a standard that the battery industry could use. In recent years, Underwriter's Laboratory (UL) has put in a lot of effort in developing a simulated internal short test method using a blunt nail test. Although the equipment used was custom built, the team at UL had some issues with getting consistent test results without penetrating the cell can. An effort was initiated between UL and JSC to carry out testing under a Space Act Agreement to standardize a method to carry out simulated internal shorts in lithium-ion cells.

UL provided test equipment for the development of this standard to NASA (figure 1). The first set of cells used for this test were Sony 18650 lithium-ion cells due to the extensive heritage NASA has with this cell design. Cells were subjected to a variety of tests before they underwent the simulated internal short test using the UL test equipment. Each test protocol included a sample size of 10 cells. One set of cells were subjected to two cycles and labeled as fresh cells. Other test sets included 200 cycles, 500 cycles, 1000 cycles, high end-of-charge voltage cycling, high-rate cycling, and cycling at low temperatures. A set of 10 cells that was rejected from a battery manufacturer and subjected to two cycles, also underwent the same crush test.

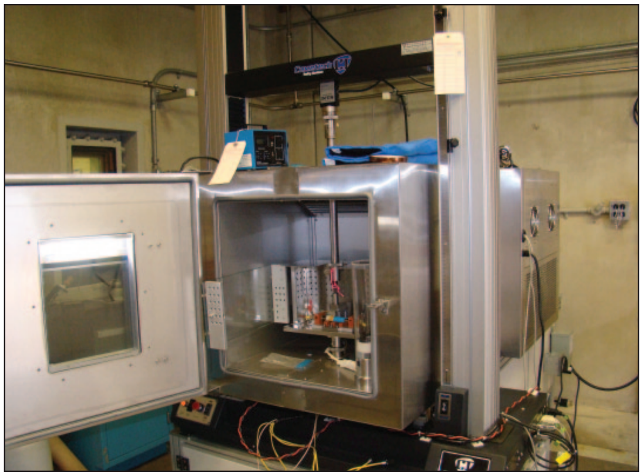

Fig. 1*. Underwriter's Laboratory test equipment at NASA Johnson Space Center for the simulated internal short test.*

At first, the team used rods of different diameters and radius of curvature to optimize the rod diameter and the rate at which the crush was carried out. A third variable that the team used as one of the test criteria was the voltage drop that indicates occurrence of the internal short. The final variable used was the location of the crush. For this last factor, all cells were x-rayed to determine the location of the aluminum (Al) tab inside the cell and marked. Literature data indicate that, in theory, thermal runaway temperatures can be produced if the internal short occurred at the location inside the cell where the Al current collector tab is in touch with the anode active material. Hence, crushes were performed at the location of the Al tab as well as 90° away from the location of the Al tab.

Cells that underwent preliminary testing with the crush test equipment, in an effort to optimize the rod diameter and the crush speed, were subjected to computed tomography (CT) scans. The CT scan data provided the extent of indentation as well as data on any damage to the cell's internal components and electrodes. Figures 2 and 3 show the CT scans depicting the indentations created by the 1/8-in. and 1/4-in. rods used under this study. The team also observed that with the 1/8-in. rod, a high speed of crush of about 0.1 millimeters per second (mm/sec) penetrated the cell can. However, with lowering the speed to about 0.01 mm/sec, a controlled internal short was obtained.

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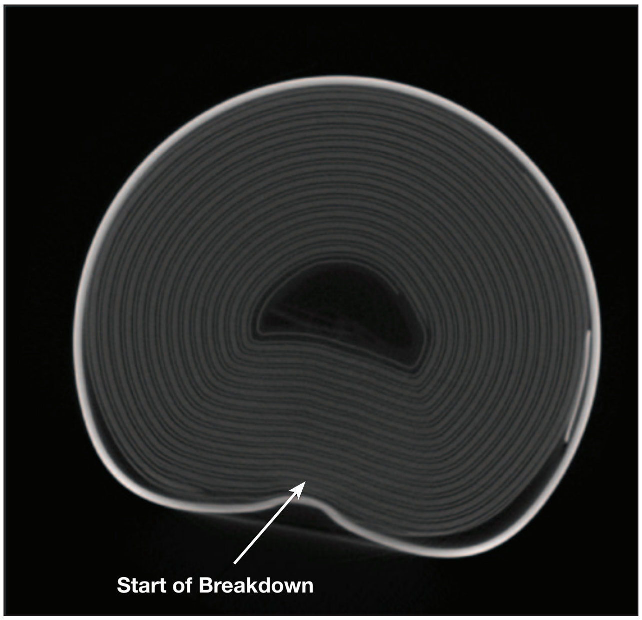

Fig. 2. *Computed tomography scan showing indentation and location of internal short with 1/8-in. crush rod.*

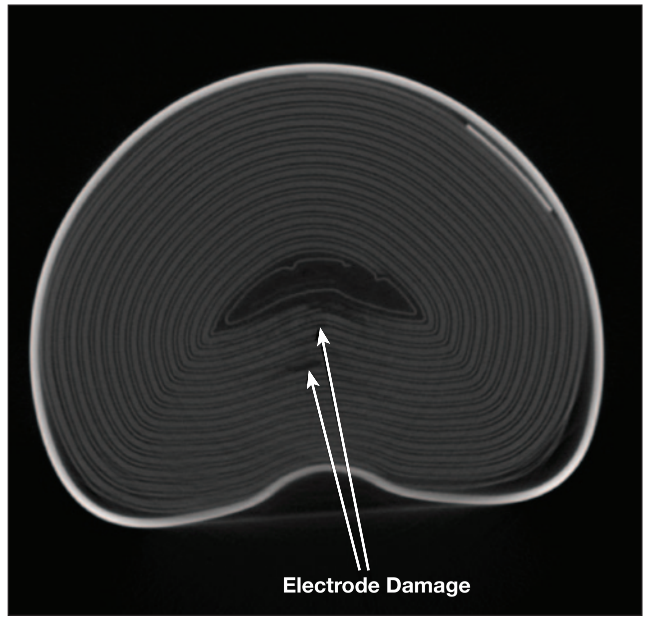

Fig. 3. *Computed tomography scan showing indentation as well as electrode damage with 1/4-in. crush rod*

The team observed that internal shorts do not result in a thermal runaway when the cell capacity is 50% the original capacity and if the cell state-of-charge was less than or equal to 50% or fully discharged. It did not matter if the cells were crushed at the location of the Al tab or away from the tab as long as the state-of-charge or capacity was as mentioned in the previous sentence.

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